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Abstract

This retrospective study was designed to examine the influence of age on the outcome of motor function and activities of daily living (ADLs) in patients with a cervical spinal cord injury (SCI). The study is based on the data registry of the EMSCI study group. Initial upper extremity motor score (UEMS) and its change over 5 months, as well as the initial Spinal Cord Independence Measure (SCIM) score did not differ between younger adults (20-39 years) and elderly (60-79 years) patients. However, the change in SCIM score over 5 months was significantly greater in the younger patient group. Initial UEMS, SCIM and ulnar compound motor action potentials (CMAP), reflecting peripheral nerve damage (motoneurons and roots), were significantly greater in incomplete compared to complete SCI, regardless of age group. *Conclusions*: The initial assessment of UEMS in combination with CMAP recordings allows an early prediction of ADLs outcomes in both younger adults and elderly subjects. The impaired translation of gain in motor score into increased ADL independence in elderly patients requires specifically tailored rehabilitation programs.

Keywords

Spinal Cord Injury, Age, Clinical management, Rehabilitation, Peripheral nerve injury

Introduction

About 50% of spinal cord injuries (SCI) occur at a cervical level. Due to the anatomy of the cervical cord, most lesions occur at levels C4/C5 and about half are complete injuries.[1] Today, the outcome of neurological deficit following SCI can be predicted reliably within the first weeks after injury.[3, 4] This allows the focusing of rehabilitative training to enhance spontaneous recovery of function early after injury. The recovery of ADLs after cervical spinal injury depends on several factors, of which the level and completeness of injury are the most important.

Compared to patients with paraplegia, activities of daily living (ADLs) and self-care are profoundly impaired in patients with tetraparesis. Nevertheless, in most patients, some rudimentary hand function can be regained through rehabilitation using training and technical aids (for a review see Wilson *et al.* 2012).[2] In cervical SCI, recovery of function not only depends on which spinal tracts are lesioned but also on the extent of any segmental damage to motoneurons and roots, i.e. to the peripheral nervous system.[5]

A main factor influencing functional outcome after SCI is age. This aspect has received little attention, despite the increasing number of elderly subjects experiencing cervical SCI as a result of trauma, particularly falls.[5-7] Studies in patients with SCI of all levels describe a positive correlation between age and neurological recovery, although that between age and the performance of ADLs was negative.[8, 9] The degree to which this observation is specifically valid in patients with a cervical SCI, which are invariably associated with an impairment of hand function and damage to both the spinal tracts and the segmental peripheral nervous system is of particular interest. The degree of damage to peripheral nerves influences functional outcome[5] and might be influenced by age. An element of spastic muscle tone is required, for example, to achieve and train a so-called tenodesis grasp which allows for rudimentary grasping movements. Furthermore, the effect of functional electrical stimulation (FES) of paralysed muscles is limited when paresis is caused to a significant degree by peripheral nerve damage. Recordings of the compound motor action potentials

(CMAP) of arm nerves represent a semi-quantitative measure of the proportion of peripheral nerve damage at an early stage after injury.[5, 10] These factors have consequences for rehabilitation approaches and to a large part determine to what extent elderly patients can regain some hand function or instead require permanent personal assistance.

This retrospective study examines the influence of age and damage to the central and peripheral nervous systems on the neurological and activity-related outcomes in patients with a cervical SCI, comparing specifically the recovery of motor deficit and ADL function of elderly patients with younger adults.

Materials and Methods

This study is based on data acquired by the spinal injury rehabilitation centers within the study group of the European Multicenter Study of Spinal Cord Injury (EMSCI).[7] Ethical approval is granted for each participating site.

Within the EMSCI network, patients with an acute SCI are examined according to a uniform protocol including clinical / neurological, activity-related and neurophysiological measures. Examinations are performed within 2 weeks and at 1, 3, 6 and 12 months after SCI. The characteristics of the spinal lesions are described according to the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI).[11] The upper extremity motor score (UEMS) represents one part of the ISNCSCI. The summed scores of five upper extremity key muscles are used for further analyses. In April 2013, a query of the central EMSCI database (which started in 2001) was performed, identifying all patients with a traumatic cervical SCI with a neurological level of injury at C4 or C5 as determined according to the ISNCSCI within the first month post-injury. Two groups were formed according to the age at injury (Table 1): i) younger adults (20-39 years) and ii) elderly (60-79 years). Middle-aged patients (aged 40-59 years) were not included. The analyses were based on examinations performed within the first month and 6 months after injury. These examinations comprised the ISNCSCI, the Spinal Cord Independence Measure (SCIM) and compound motor action potentials (CMAP) to ulnar nerve stimulation.[3, 10] The mean amplitudes of both sides were used in the analyses. The changes in the assessments were evaluated as differences between the two time-points (i.e. recordings at 6 months minus those obtained within the first month). Comparisons between the two age groups were calculated using independent T-Tests and Cohen's Chi-Square as appropriate or in the case of associations with the Spearman Rank Correlation. Results were considered statistically significant where $p \leq 0.05$. Figures are presented as mean ± standard deviation (SD). SPSS statistics 19 for Windows (IBM Corp.) and Excel 2010 for Windows (Microsoft Corp.) were used for the analyses.

Results

Overall, 413 patients with cervical SCI matched the inclusion criteria and were included in this study, 209 (50.6%) motor incomplete (i.e. ASIA Impairment Scale [AIS] C and D) and 204 (49.4%) motor complete (i.e. AIS A and B). There was a significant ($p<0.001$) association between motor completeness and age group. Younger adults predominantly had a motor complete SCI. Correspondingly, most elderly patients experienced a motor incomplete SCI (Table 1). Not all data were available at the second time point for all patients. This loss was approximately equally distributed between the two age groups. Precise numbers of available data are provided for each assessment.

Motor complete SCI

The proportion of patients with the most caudal preserved *neurological level of injury* at C4 was similar in the younger adult (62.6%) and the elderly (61.5%; n.s.) group. In the remaining patients, the lowest preserved level was at C5. The length of stay of younger adults classified as inpatients was 207.5±100.7, while the same metric was 179.7±82.4 days (n.s.) in the elderly group. The distribution of initial AIS A and B was also similar in both age groups (younger adults: A: 71.9%; and elderly: A: 76.9% n.s.).

An *ISNCSCI at 6 months* was assessed in 99 (of 139, 71.2%) of younger adults and 50 (of 65, 76.9%) elderly patients. In the younger adults group, 21.2% changed from a motor complete to a motor incomplete SCI. In the group of elderly patients, the proportion of change from motor complete to incomplete was slightly higher (34.0%; n.s.).

Table 2 shows the mean initial values of *upper extremity motor score (UEMS)* and *spinal cord independence measure (SCIM)*, including changes over 5 months for the two age groups. The respective initial values of and subsequent changes in UEMS after 6 months could be assessed in 136 and 102 (i.e.97.8% and 73.4%) younger adults and in 65 and 50 (i.e. 100.0% and 76.9%) elderly subjects. Initial values and subsequent changes in the SCIM

score were available in 122 and 86 (i.e. 87.8% and 61.9%) younger adults and in 57 and 42 (i.e. 87.7% and 64.6%) elderly subjects.

For the motor complete subjects, the mean UEMS was initially similar in both groups of patients ().The same was true for changes in UEMS at 5 months (table 2). Correspondingly, the initial mean total SCIM score differed little between the younger adults and elderly patients. The change in total SCIM score at 5 months, however, was significantly greater ($p<0.001$) in the younger adult compared to the elderly group (table 2 and fig 1A). This difference in SCIM change was reflected in all three subscales of the score.

Motor incomplete SCI

The proportion of motor incomplete patients with the most caudal preserved *neurological level of injury* at C4 was similar in the younger adults (49.3%) and the elderly (53.0%; n.s.) group. In about half of these patients, the lowest preserved level was at C5. (Among motor complete patients, only in about one third was the lowest preserved level at C5, $p<0.05$). A central cord syndrome-like pattern of neurological deficits was present in 20.5% of the younger adult and 25.0% of the elderly group (n.s.).

The mean *length of stay* was assessed in 46 (61.3%) in the younger adult group and in 93 (69.4%) of the elderly subjects. As to be expected, length of stay was shorter in the incomplete than the complete group ($p<0.001$), but did not differ between the younger adult (117.6±80.5 days) and elderly (113.8±68.1 days; n.s.) subjects. The distribution of the initial *AIS score* in the motor incomplete group was also similar for the younger (AIS C 46.7%, AIS D 53.3%) and older (AIS C 35.8%; AIS D 64.2%; n.s.) patients. At 5 months, the change in AIS (assessed in 42 (56.0%) younger adult and 79 (59.0%) elderly subjects) was similar (n.s.) in both groups.A change from AIS C to D occurred in 33.3% younger adult and 29.1% elderly subjects. The proportion of patients with an initial AIS D remained approximately the same (middle aged 52.4%; aged 59.5%; n.s.).

Table 3 shows the mean initial values (with SD) of *UEMS* (assessed in 73 [97.3%] younger adult and 132 [98.5%] elderly subjects) and *SCIM* (assessed in 64 [85.3%] younger adult and 117 [87.3%] elderly subjects), as well as the corresponding changes at 5 months from the group of younger adult (UEMS assessed in 43 [57.3%] and SCIM assessed in 41 [54.7%] subjects) and elderly (UEMS assessed in 79 [59.0%] and SCIM assessed in 73 [54.5%] subjects). The mean initial UEMS was identical in both groups. The change in this score over 5 months did not differ significantly between the groups. Correspondingly the initial total SCIM score did not significantly differ between younger and older patients. However, the change in the SCIM score at 5 months was significantly higher ($p<0.01$) in younger compared to elderly patients (table 3; fig. 1B). This difference in the change in SCIM score was significant for all three subscales of the score.

Neurographic recordings

Table 4 shows the mean values of ulnar *compound motor action potentials (CMAP*) in the motor complete and motor incomplete cervical SCI groups.

In the *motor complete* SCI group, CMAP recordings performed within one month of injury were available for 50 (36.0%) younger adult and 25 (38.5%) elderly patients. Changes in CMAP values could be obtained in 30 (22.0%) younger adult and 16 (24.6%) elderly patients. The initial CMAP amplitude and its change at 5 months did not differ between the age groups. The average CMAP amplitude did deteriorate in all patients with a motor complete injury.

In the *motor incomplete* SCI group, initial ulnar CMAPs were recorded in 27 (36.0%) younger adult and 63 (47.0%) elderly subjects and the changes in CMAP at 5 months in 13 (17.3%) younger adult and 29 (21.6%) elderly subjects. Ulnar nerve CMAP values were initially slightly larger in amplitude in the younger subject group ($p<0.05$). However, the change in CMAP amplitude at 5 months was similar for both age groups (table 4).

Table 4 highlights that in both age groups (younger adults: $p<0.001$; elderly: $p< 0.01$), CMAP amplitudes at 5 months after injury were significantly greater in motor incomplete patients than in those with a complete SCI. Figure 2 shows the associations between the changes of the CMAP and the SCIM scores for both, motor complete and incomplete patients. The correlations between the two variables were significant ($p<0.01$ and $p<0.05$) for both the group of young adults (fig. 2A) and the elderly patients (fig. 2B).

Discussion

The aim of this study was to evaluate the influence of age on the recovery of neurological deficit following cervical SCI and its relation to the improvement in patients' performance of ADLs, which are strongly determined by hand function. In an earlier study which included patients with all levels of spinal cord injury, a discrepancy between the recovery of neurological deficit and ADLs was found.[9] While the recovery of neurological motor deficit was described as slightly better in elderly compared to younger subjects, this gain in motor score was not translated into a corresponding improvement in ADLs, such as locomotion.

In cervical SCI, a different outcome may be anticipated, given that many ADLs are crucially dependent on hand function. In addition, a cervical (compared to a thoracic) injury is associated with a combination of damage to both peripheral and central nervous structures which determines the overall neurological deficit. An additional aim of the study, therefore, was to evaluate the influence of motor neuron / root damage on outcome in elderly compared to younger adult subjects with an SCI. All these aspects are expected to have an impact in rehabilitation, especially of hand function. The main observations presented are the followings. Firstly, corroborating an earlier report, length of stay did not differ between the elderly and the younger adult group.[12] Secondly, motor complete injuries was more prevalent in the younger group of patients, and motor incomplete injuries accordingly more common in the older group, in line with other multi-center studies.[13-15] Already low energetic traumata, such as falls can in elderly subjects lead to SCI due to the combination of a narrow spinal canal and degenerative changes in the cervical spine. Thirdly, in the complete and incomplete SCI groups, the initial UEMS and the activity-related SCIM score did not differ between the two age groups. However, while no significant change in UEMS at 5 months was observed, the improvement in SCIM score at the same timepoint was significantly greater in the younger group. Lastly, UEMS and SCIM scores were significantly greater in motor incomplete compared to complete SCI subjects both in terms of their values at baseline and the changes in scores at 5 months. Correspondingly, the initial amplitude of the

ulnar CMAP was larger and the change in 5 months greater in the motor incomplete group when compared to the motor complete group, with no significant difference seen between the younger and older patient groups.

Influence of age on AIS, UEMS and SCIM

In the *motor complete SCI* group, 21% (younger adults) and 34% (elderly) patients converted to incomplete SCI, indicating a slightly better recovery of neurological deficit in elderly patients. Other studies on populations of patients including all levels of an SCI reported that between 70%[16] and 90%[17] of patients do not convert from AIS A to a lower grade of injury.

In complete SCI patients, the most caudal preserved level was usually higher (C4) compared to incomplete (C5) SCI subjects. This difference might be due to the fact that although the primary lesion level is similar, injuries with stronger impact forces cause a motor complete SCI associated with an expansion of tissue damage up to the C4 level.

The initial values of upper limb motor and SCIM scores were similar in both age groups. This was also true for changes in the UEMS at 5 months. In accordance with earlier studies, the average gain in motor points over 5 months was 10 motor points.[18] The improvement in SCIM score at 5 months was greater in the younger adult group than that seen in elderly subjects. Obviously the younger adult patients were better able to harness the gain in voluntary muscle activation and translate it into improved ADL performance as measured by the SCIM. The distributions showed a somewhat broader dispersion of the SCIM gains in the group of young adults compared to the corresponding values in the elderly which were more clustered in the lower area of the change scale (fig. 1A). There was a larger proportion of young patients with considerable improvement in SCIM.

Similar observations were made in *motor incomplete SCI*. The initial values and subsequent changes in UEMS over 5 months were similar in both age groups. The number of patients who showed a change in the AIS grade from C to D was slightly higher in the group of aged

patients, a difference which failed to meet significance criteria. The distribution of SCIM gains (fig. 1B) indicates strong improvements in the younger group while the changes in score were more equally distributed in the elderly.

The initial SCIM score also did not differ between the age groups. However, the improvement in the total SCIM score was significantly greater in younger adults compared to the elderly subjects, a result comparable to that seen amongst the motor incomplete population described above, with younger subjects better placed to translate voluntary muscle contraction gains into meaningful ADL performance. This may explain previous reports of greater activity-related deficits in elderly patients with SCI.[8, 12] With the knowledge that also elderly patients show a recovery of motor deficit it becomes challenging to design novel rehabilitation strategies which focus on a better age-related translation into function.

The recovery in AIS, UEMS, and SCIM was greater in motor incomplete SCI than in complete SCI, i.e. the completeness of lesion can serve as a prognostic factor.[4] Within the group of individuals with incomplete SCI, central cord syndrome (CCS) is reported to be more common in aged subjects[15] and, while not reaching significant, this was also the case in our study. However, this fact has probably little influence on outcome, as no difference was found between incomplete SCI groups (Brown-Sequard and central cord syndrome). [19]

Influence of age and peripheral nervous system damage on outcome

The recordings of ulnar CMAP reflect the amount of peripheral / motor neuron damage.[3,10] There was little difference in the amplitude of ulnar CMAP nor significant changes from baseline amplitude at 5 months between younger adults and elderly subjects with complete or incomplete SCI. However, when age groups were collated, the initial CMAP amplitudes and subsequent changes at 5 months were greater in the group of patients with incomplete SCI. Therefore, CMAP amplitudes evidently reflect not only the damage of the peripheral motor system but the sum of sensorimotor deficits and their changes over time. Despite an

upper level of lesion of C4 and C5, respectively, the damage of peripheral nerves / motor neurons was reflected in the ulnar CMAP despite this nerve mainly being supplied by the roots C7 to T1. This discrepancy indicates that the damage to nervous tissue extends over several segments in severe SCI.

In addition, our data shows that changes of the neurographic recordings (CMAP amplitudes) and the ability to perform daily life activities (SCIM) are independently related. Consequently, CMAP values can be used to predict outcome. A reduction in CMAP amplitude indicates, at an early stage following injury, damage to the peripheral motor system (motor neurons and roots). This measure can provide a semi-quantitative estimate of the involvement of roots and motor neurons in cervical injury and reflects the severity of the injury.

Conclusions

An important aspect of this study is the demonstration that, while neurological deficit and its recovery over time do not differ between younger adults and elderly patients, greater-activity related limitation in recovery persists in older patients. The observation that the recovery of the neurological deficit after an SCI does not depend on age is somewhat surprising. It indicates that also elderly subjects can profit from rehabilitation procedures, if the gain in voluntary motor control succeeds to be translated into activities (e.g. improvement of hand function). This might happen if rehabilitation approaches become focused on a few activities required in daily life and if training becomes adapted to the abilities of the individual subject. This mandates a search for specific rehabilitation approaches at an early stage after injury to allow better translation into activity-related recovery in elderly patients. There is obviously a need to develop rehabilitation programs specifically tailored to the requirements of older adults.[14] A program so adapted should focus on the training of a few essential aspects of ADLs.

In addition and independent of age, both the UEMS and the ulnar nerve CMAP can serve as markers for an early prediction of the outcome of sensorimotor deficit after injury. This allows an early planning of rehabilitation procedures to be applied to an individual patient.

Methodological considerations

This study has an explorative nature and deals with a subgroup of SCI patients. Only the collective effort of numerous SCI rehabilitation centers through the EMSCI network made it possible to include a reasonable number of patients. Although there are instruction courses and regular informal meetings, it is possible that the variability introduced by the many testers at different study sites is greater than in a situation in which a small number of experts at one center assess patients.

The clinical assessments comprise categorical items which are summed (e.g. UEMS or SCIM). In the statistical analyses, these summed scores are often handled as if they were continuous variables. This may introduce erroneous results if assumptions of tests are violated. It is possible to assess whether the treatment of this kind of data is justified in a particular situation (eg. using a Rasch analysis), but this was beyond the aims of the present study.

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Author Disclosure Statement

No competing financial interests exist.

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Figure legends

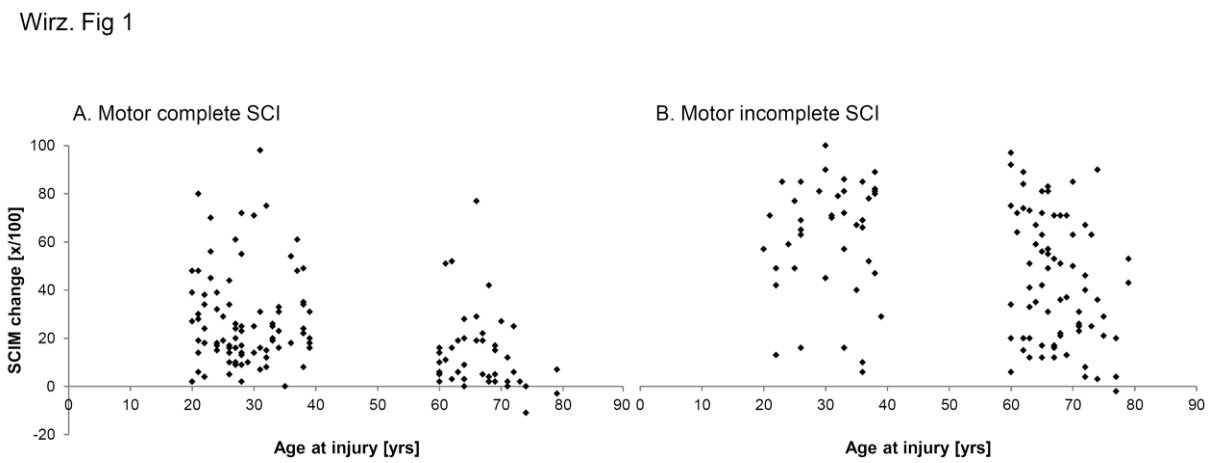

Figure 1

Differences in SCIM score changes (maximum score: 100) at 5 months after injury between young adult- and elderly patients A. motor complete cervical SCI ($p<0.001$, table 2); B. motor incomplete cervical SCI ($p<0.01$, table 3).

Wirz. Fig 2

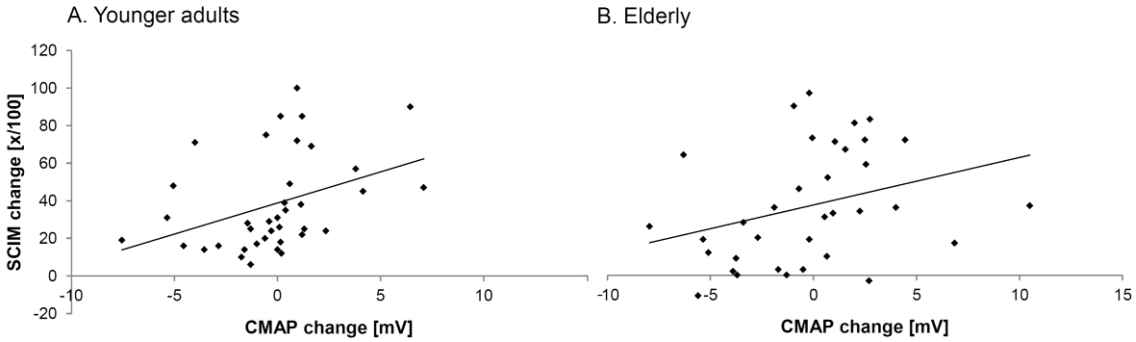

Figure 2

Distributions and rank-correlations between SCIM (maximum score: 100) and CMAP (mV) changes at 5 months after injury. A. younger adults ($r=0.47$, $p<0.01$); B. elderly ($r=0.42$, $p<0.05$).

Table 1. Characteristics of subjects with cervical SCI

		Motor complete		
		No	Yes	Total
Age group	Younger adults	75 (35.8)	139 (68.1)	214 (51.8)
	Elderly	134 (64.1)	65 (31.9)	199 (48.2)
	Total	209 (100)	204 (100)	413 (100)

Comparison between completeness of cervical SCI and age at injury. Younger adults = 20-39 years; elderly = 60-79 years. Note a significant ($p<0.001$, Chi-square) association between motor completeness and age group. Figures represent number of patients with percentages in parentheses.

Table 2. Motor complete SCI

		Younger adults (20-39y)	Elderly (60-79y)
UEMS	Initial	11.8 (9.0)	13.0 (13.5)
	Change	9.4 (9.4)	8.9 (10.9)
SCIM	Initial	8.5 (7.2)	7.6 (7.6)
	Change	27.7 (19.8)	14.2 (16.8)***

Mean values (with SD) of the initial upper extremity motor scores (UEMS) and of spinal cord independence measure (SCIM) scores and changes in these scores over 5 months in younger adults and elderly patients with a motor complete cervical SCI.

*** $p<0.001$

Table 3. Motor incomplete SCI

		Younger adults (20-39y)	Elderly (60-79y)
UEMS	Initial	24.0 (12.3)	24.0 (11.6)
	Change	16.7 (10.9)	13.6 (8.0)
SCIM	Initial	22.3 (19.6)	18.8 (16.4)
	Change	61.7 (24.3)	43.7 (26.6)**

Mean values (with SD) of the UEMS and SCIM scores and changes in these scores over 5 months in younger adults and elderly patients with an incomplete cervical SCI.

** $p<0.01$

Table 4. Peripheral nerve damage

		Younger adults (20-39y)	Elderly (60-79y)
Motor complete			
CMAP (mV)	Initial	4.9 (3.9)	4.38 (3.2)
	Change	-1.1 (2.6)	-1.9 (2.5)
Motor incomplete			
CMAP (mV)	Initial	8.5 (4.35)	6.8 (3.3)*
	Change	1.5 (3.2)	1.4 (3.6)

Mean values of the ulnar compound action potentials (CMAP; mean of both arms) changes in the mean over 5 months in younger adults (20-39 years) and elderly (60-79 years) with motor complete and incomplete cervical SCI.

*$p<0.05$

With both age groups taken together, initial values and subsequent changes at 5 months were greater in the motor incomplete patients ($p<0.001$).